

Asymmetrical Planetary Nebulae II: From Origins to Microstructures
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Mid-IR Imaging of AGB Circumstellar Envelopes

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Abstract. AGB stars, the precursors of Planetary Nebulæ, exhibit high rates of mass loss and eject material in the form of a slow (10-20 km/s), dusty molecular wind. The general belief that the dust component of AGB circumstellar envelopes have smooth density profiles and spherical symmetry have recently been shaken by new high resolution images, showing that clumpy and asymmetric structures, analogous to the ones observed in Planetary Nebulæ, can be present even before the end of the AGB. To illustrate how and when these structures appear, and possibly to address the question of how they may shape the subsequent evolution of these systems, we have started a campaign of mid-IR high spatial resolution imaging of a selected sample of AGB targets. We want here to illustrate our technique, developed for the mid-IR camera MIRAC3, and to show the first results obtained at the NASA Infrared Telescope Facility.

1. Looking for asymmetrical progenitors of PN

Intermediate and low mass stars ($1-8 M_{\odot}$) are characterized, in the phase known as Asymptotic Giant Branch (AGB), by the formation of an optically opaque circumstellar envelope of gas and dust, which will later evolve into a Planetary Nebula. The detailed physical processes involved in this phenomena are still uncertain, but there are growing evidences that they are connected to radial stellar oscillations and non uniform density distributions (Lebertre & Winters 1998; Fleisher et al. 1992).

Recent observations at different wavelengths support the idea that these inhomogeneities can propagate in the circumstellar envelope, giving rise to structures with strong deviations from spherical symmetry. Clumpy structures in the

dust forming regions of the C-rich AGB star IRC +10216 were found by near-IR masking and speckle interferometry at Keck and SAO telescopes (Monnier et al. 1997, Weigelt et al. 1998). A sequence of detached dust shells were also found around this source by deep optical imaging (Mauron & Huggins 1999), suggesting a complex mass loss history similar to the one that characterized the more evolved post-AGB “Egg Nebula” (Sahai et al. 1998), or the O-rich Mira R Hya (Hashimoto et al. 1998). All these observations suggest the idea that the asymmetry observed in many PN already starts during the AGB, where it shapes the evolution of the circumstellar envelope towards the Planetary Nebula phase.

Mid-IR is the ideal spectral range to image the spatial distribution of dust in the circumstellar environment of AGB stars, and provides an effective diagnostic tool to derive the physical and chemical parameters of circumstellar dust (Marengo et al. 1999). The availability of a large sample of spatially resolved AGB envelopes in the mid-IR would be essential to improve our knowledge of the mass loss processes at the end of the AGB, in search for departures from spherical symmetry and the “steady mass loss” $1/r^2$ radial density profile of the stellar outflow.

2. Modelling the envelope emission

In most cases, the thermal radiation coming from AGB circumstellar envelopes is too faint to be detected around the bright AGB star at the center of the system. Furthermore, only the nearest sources are extended enough to be spatially resolved with the angular resolution provided by available IR telescopes.

For these reasons we have compiled our target list fitting all the available IRAS Low Resolution Spectra (LRS) of AGB sources with the public domain radiative transfer code DUSTY (Ivezić & Elitzur 1997). Each computed radial brightness profile was then transformed into a two dimensional image, convolved with the instrumental PSF, and resampled into the MIRAC3 final image array. Gaussian noise was finally added to produce a peak S/N of $\sim 1,000$, as expected for the real observations. Only sources showing a detectable excess emission above the instrumental Point Spread Function (PSF), in a minimum area of 6–8 arcsec in diameter, were selected for observations.

3. Diffraction limited imaging in the mid-IR

The circumstellar dust emission predicted by our models is typically characterized by a compact component, only partially resolved as an enlarged (in terms of the FWHM) PSF, plus a faint “halo” that can be separated by the “wings” of the PSF only when the S/N is of the order of $\sim 1,000$, or larger. For a positive detection of these two components is necessary to maximize the achievable angular resolution and sensitivity. To meet these requirements, we are using a technique based on the “fast readout” mode of the camera MIRAC3, that allows the acquisition of frames with very short integration times (0.1–0.2 sec), capable of “freezing” the atmospheric seeing.

The source is imaged with a standard nodding and chopping technique, in order to remove the background signal, and dithered on the array to obtain for

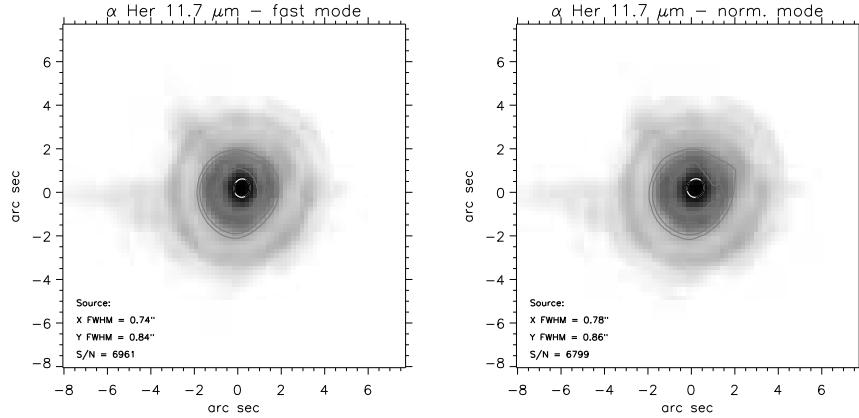


Figure 1. The reference star α Her at $11.7 \mu\text{m}$. The image on the left was obtained using MIRAC3 fast mode, coadding about 1,600 single exposures of 0.17 sec (272 sec total); on the right is the coadding (without drizzling) of 80 exposures of 10 sec each (800 sec total). Note the smaller FWHM of the fast mode image, and its higher S/N (despite the shorter total integration time).

each beam a number of images that can be of the order of ~ 500 . Each image is then rebinned on a sub-pixel grid to increase the PSF sampling, shifted and coadded.

To maximize the sampling of the dithered images without degrading the angular resolution, we have adopted the “drizzling” method developed by Fruchter & Hook (1997), whenever the number of single frames available for the coadding is sufficient to provide an uniform distribution of the dithered “drops” on the final image (tipically 200-250 frames for each beam). As shown in Fig. 1, this technique allow to increase the S/N reducing the PSF FWHM, producing images that are virtually diffraction limited, and largely independent from the atmospheric seeing.

One of the most extended sources observed in June 1999 run with MIRAC3 at IRTF is the O-rich semiregular variable W Hya. We present here its $18 \mu\text{m}$ image, compared with the reference star α Boo (Fig. 2). Note the much larger FWHM of the AGB source, and its oval shape elongated in the N-S direction, compared to the more compact and symmetric image of the reference star. In June 1999 run, a total of 10 AGB sources where observed at 8.8, 9.8, 11.7, 12.5

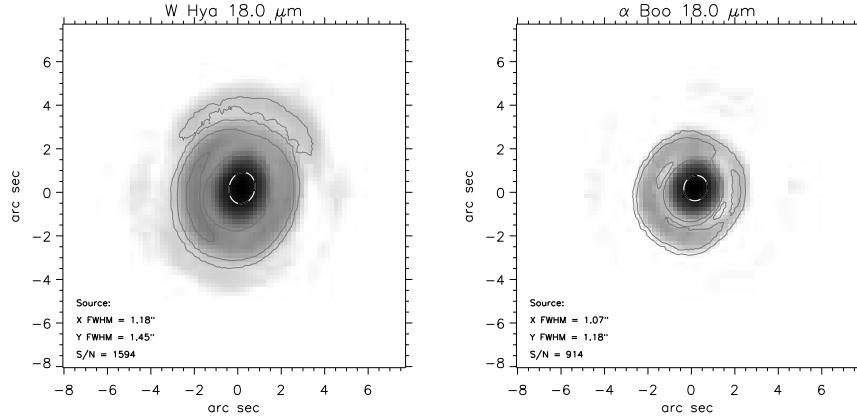


Figure 2. $18 \mu\text{m}$ images of the O-rich semiregular variable W Hya, and the bright IR standard star α Boo as PSF reference. Contours levels indicate 0.01, 0.02, 0.05 and 0.5 of the source and reference maximum.

and $18 \mu\text{m}$; the analysis of the collected data is currently in progress, and further observing runs are scheduled for IRTF and MMT.

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